ELECTRICAL CONTACTS FOR PULSED POWER SYSTEMS

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Introduction

Electrical contacts are present wherever two conductors join, including busbar joints and device connections. Electrical contacts for pulsed power applications are normally designed to be low voltage, metal-to-metal contacts. This may be accomplished in one of two ways. The first is to join the two contact surfaces together with enough force to be sure that the contact does not arc during the pulse. Design techniques often involve using contact sizes and forces established for dc or steady state operation (1). Another technique is to weld or braze the surfaces together (2). Our concern here is with the first method.

Applying a force to obtain a contact can pose a maintenance problem after several pulses. If the initial contact force is not sufficient, the contact will collapse slightly during each pulse. This causes the contact force to decrease, and if the contact force is not periodically increased, the contact will eventually fail. We have developed a technique to predict the force needed to ensure stable operation of a contact through multiple pulses. We describe the technique and provide experimental validation in this paper.

Contact Growth

In general, contact between two surfaces occurs at a finite number of points due to roughness in both surfaces. In electrical contacts, current flows through these points, known as "A-spots". In a "transient contact," the contact spots are not in thermal equilibrium. Contacts in many pulsed power applications are transient contacts. This is due to the high current densities and the short time duration of the current pulse.

The initial contact area, A_O, is given by Holm (3) (for plastic contacts) by:

$$F = A_O H \tag{1}$$

where F = the applied force
A_O = the initial contact area,
and H = the hardness of the softer of the two contact materials.

The initial contact area A_O may be expressed in terms of the number of "A-spots" of radius a as follows:

$$A_O = N\pi a^2 \tag{2}$$

where N = the number of spots.

Holm calculated the time dependent temperature distribution in the A-spot. He introduced a dimensionless time parameter, z, given by:

$$z = \frac{\lambda}{\rho C_p a^2} t \tag{3}$$

where λ = the thermal conductivity
ρ = the density
and C_p = the specific heat of the contact material.

For low values of z, thermal conduction away from the spot is insignificant. In a related paper (4), we showed that for values of z less than 0.5, the contact spot is adiabatic. Figure 1 shows the adiabatic region of operation as a function of the A-spot radius and time. Most pulsed power applications for contacts fall in the adiabatic region.

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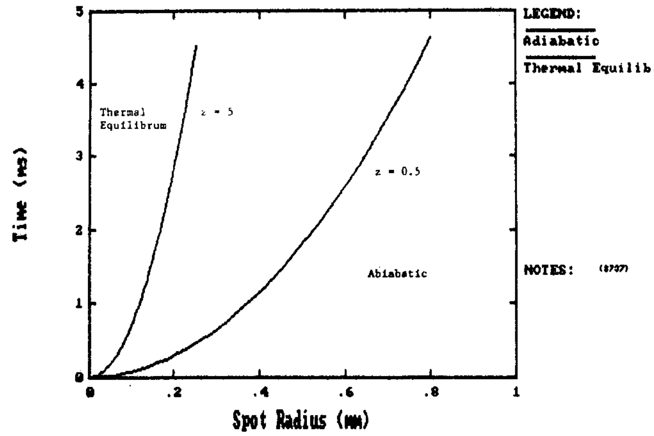

Fig. 1. The contact spot is adiabatic for large spot radius or short times.

If the contact spot is adiabatic, only the current heats the contact spot, and the electrical action governs the contact temperature. Electrical action is defined by the equation:

$$\int j^2 dt = \int_{T_0}^{T_0+\Delta T} \frac{\rho C_p}{\eta} dT = g \tag{4}$$

where j = the current density through the contact spot
T = the temperature
η = the resistivity
and g = the action constant.

Equation (4) shows that the action constant, g, is an indirect measurement of the temperature. There are specific values of the action constant which correspond to the material softening, melting, and vaporization temperatures.

In an adiabatic electrical contact, the initial contact spot bears the mechanical load and carries the current. As the spot temperature increases above the softening point, the contact softens and can no longer bear the mechanical load. The contact spot collapses until a cold contact area sufficient to bear the mechanical load is established. The softened area continues to carry current. The growth of the contact area appears experimentally as a decrease in the contact resistance as shown in Figure 2. Contact collapse and growth over several pulses results in reduction of the contact force. To prevent contact failure, the contact force must be periodically increased.

Design of a Contact

Stable operation for many current pulses requires that the contact area must not be heated to the softening point during a single pulse. If A_O is to remain constant, then equation (4) becomes

$$\int I^2 dt = g_S A_O^2 \tag{5}$$

where $\int I^2 dt$ = the electrical action
and g_S = the action constant at which softening occurs.

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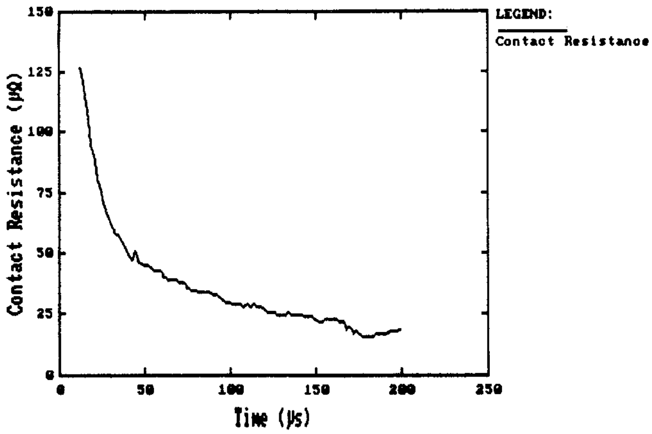

Fig. 2. The contact resistance decreases as the contact area grows during a pulse.

Equation (1) shows that A_0 depends only on the applied force and the hardness of the contact material. Therefore, at the softening point

$$\int I^2 dt = g_S \left(\frac{F}{H}\right)^2 \tag{6}$$

and the contact force must be at least

$$F = \left[\frac{H}{g_S^{1/2}}\right] \left(\int I^2 dt\right)^{1/2} \tag{7}$$

The minimum force described by Equation (7) depends only on the material hardness, softening action, and the pulse action.

Experimental Validation

We performed a series of experiments to confirm our design technique. The concept of the apparatus is shown in Figure 3. A pneumatic actuator presses the contactor (on the right) onto the disk. The disk material was CDA110 half hard copper, and the contactor was annealed CDA110. The hardnesses of the disk and contactor were 811 MN/m² and 240 MN/m² respectively. The contact force was 225 N for each test. A 20 kJ capacitor bank supplies the current pulse to the contact. A typical current pulse is shown in Figure 4. The maximum current used for these tests was 12 kA.

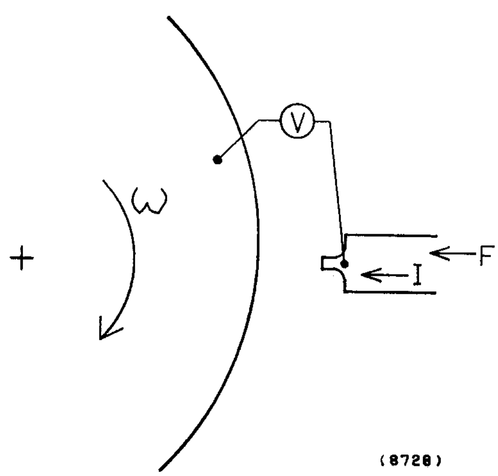

Fig. 3. A simple pin on disk apparatus was used.

The disk was held stationary and the contactor actuated onto the disk. The capacitor bank was fired and the current and the voltage across the contact were recorded. We fired several current pulses through the contact while maintaining contact force. Each pulse had a higher peak current (hence a higher pulse action) than the preceding pulse.

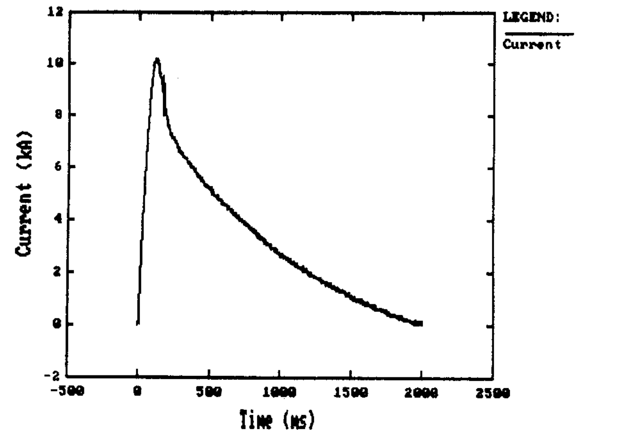

Fig. 4. The current pulse is typically a few milliseconds long.

From our measurements, we calculated the contact resistance as a function of time. We saw no change in the contact resistance until the peak current was 10 kA. The corresponding pulse action was 48 kA²s. The contact resistance is shown in Figure 5. Our results are consistent with a softening action constant g_S of 55000 A²s/mm⁴. This value of g_S is 68% of the melt action of the copper contactor.

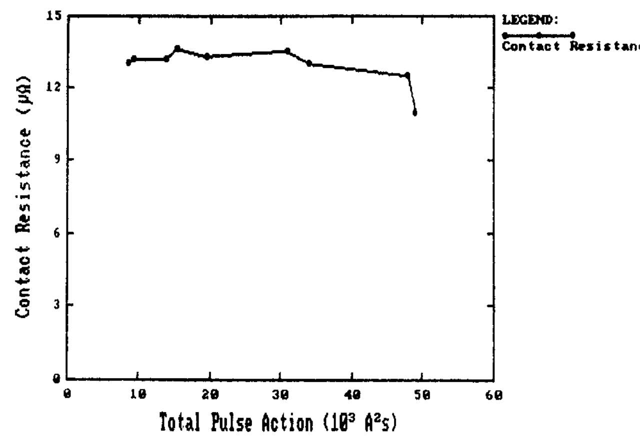

Fig. 5. The contact resistance remains constant until the contact area collapses.

Conclusions

Based on our experimental observations and our design relationship, we conclude that the contact area is indeed adiabatic. The pulse action and the contact material govern the behavior of the contact. There is a minimum force which provides a contact area which will not grow even if several pulses are applied. This minimum force depends only on the contact material and the pulse action. For a particular pulse action, applying the minimum force on the contact will eliminate contact growth. The minimum required force increases with current level and pulse duration. Soft materials and those with high action to soften, such as annealed copper, require the least force. Finally, care must be taken to ensure that the high magnetic forces generated in pulsed power systems do not "unload" the bus contacts.

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